

Mill scale results on TMP pulping of southern pine with pressurized chip pretreatment

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ABSTRACT

The use of high compression screw devices to remove extractives from pine wood furnishes has obvious economical implications regarding the consumption of chemicals used for bleaching and pitch control. The application of high compression chip screw devices on pine chip furnishes has been limited, however, due to the susceptibility of pine to fiber breakage at elevated levels of compression. A modified chip pretreatment process with pressurized inlet has been previously proposed to increase thermal softening of the fibers prior to and during chip compression, thereby reducing fiber damage to the chip structure and permitting increased levels of extractives removal. This study presents results of the pressurized chip pretreatment at a southern U.S. newsprint mill.

The effect of the chip pretreatment on pulp properties, extractives content, COD, and pitch chemical usage are reported. The process is characterized at several levels of inlet pressure (0, 10, and 15, 20 psi), including bypass of the chip pretreatment. Both industrial scale results and pilot scale results are presented.

Keywords

Mechanical pulping, thermomechanical pulping, chip pretreatment, wood compression, single disc refiner, energy reduction, wood extractives, *Pinus taeda*, Bowater Calhoun

Introduction

The use of pine species in newsprint production has steadily increased, primarily due to the higher wood growth rates and related reductions in wood raw material costs compared to northern spruce furnishes¹. The utilization of pine, however, has its drawbacks including higher wood extractives content, higher fibre coarseness, and higher specific energy requirements to attain a similar level of fiber development compared to spruce furnishes². Higher levels of wood extractives in pine thermomechanical pulp (TMP) require additional chemical costs to deal with pulp bleaching and pitch deposits at the papermachine. Such constraints have resulted in an increasing interest from pine printing paper producers for improved process alternatives to

reduce costs associated with higher extractives and refiner energy consumption.

A logical area for extractives removal is in the wood chips at the front end of the process. Compression of the chips in a high compression screw device not only reduces the extractives level prior to refining, but also permits a concentrated pressate stream rich in extractives to pass directly to effluent treatment. The application of high compression screw devices in pine TMP systems, however, has been limited due to a high degree of fibre damage and fines generation³. This was primarily due to insufficient heating and softening of the pine chip structure during compression at the shear rates of a typical commercial high compression screw press.

A new compression pretreatment process (RT Pressafiner™) was introduced by Andritz Inc. in 1997, which compresses and reorients the wood chip structure at pressurized inlet conditions⁴. The pressurized inlet permits a higher degree of heating and softening prior to compression at elevated compression levels. This in turn permits a higher degree of extractives removal and a higher degree of axially separated fibers with less fibre damage.

Extensive pilot plant pressurized refining studies have been conducted using the pretreatment process on North American spruce⁴, Norway spruce⁵ (*Picea abies*), and pine⁶ (*P. taeda*, *P. caribaea*) chip furnishes. The pine pulps with the compressive pretreatment had 0.8%-1.2% lower DCM extractives content compared to the control pulps. SEM analysis of the pretreated chips indicated a significant degree of axial fiber separation following the compression process^{4,5}, with much less fines generation compared to chips compressed under atmospheric conditions⁴. Reductions in specific energy averaging approximately 125 to 175 kWh/ODMT were reported from the pilot plant studies with TMP pulps produced using the compressive pretreatment compared to control pulps produced without the pretreatment. Two studies also reported additional energy savings were available by combining the compressive pretreatment and higher intensity refining conditions, with reported total reductions in specific energy of 440-511 kWh/ODMT and 461-549 kWh/ODMT for northeastern spruce⁴ and Norway spruce⁵, respectively. Partial defibration of the wood chips with exposed fiber surface following pretreatment was proposed as an explanation regarding the improved amenability of the chip structure to higher intensity refining conditions. An alternative or supporting explanation was that refining untreated chips generates a higher proportion of damaged fibers and fines, primarily when the wood chips are forced into the breaker bar and inner refining zone of the refiner plates. Another explanation is untreated chips contribute to higher refiner load swings and instability.

The first commercial RT Pressafiner pretreatment system was started in July 1999 at the Bowater newsprint operation located in Calhoun, Tennessee.

Each pretreatment configuration includes a rotary valve with pressurized discharge, pressurized transfer conveyor and MSD Impressafiner with pressurized inlet capability. Figure 1 illustrates the control screen for the chip pretreatment at Calhoun. A two line single disc TMP refiner system was supplied by Andritz, complete with RTS (low retention-high temperature-high speed) refining capability and steam recovery. The exhaust steam from the pressurized inlet side of pretreatment is collected along with the "dirty" steam from refining and sent to a turpentine condenser unit prior to clean steam recovery. The Bowater Calhoun division is the largest producer of newsprint in North America. The TMP operation consists of eight refining lines; six double disc refining lines (1-6) and two new single disc refining lines (7-8). Important criteria to Bowater on the project included pulp quality, extractives content and specific energy requirements.

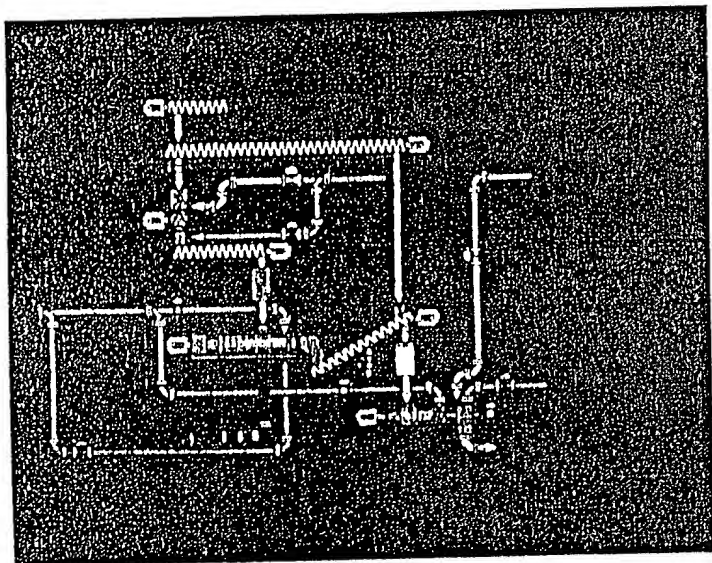


Figure 1. Chip Pretreatment Configuration

This paper discusses results to date obtained at the Bowater Calhoun newsprint division using the new chip pretreatment process. The implications on extractives and COD removal, pulp properties, specific energy requirements, and refiner stability are presented. Results are presented from operating during both the winter and summer periods. Pilot plant results on Bowater Calhoun's pine chip furnish using a similar RT Pressafiner pretreatment configuration are also presented.

Experimental

Southern pine wood chips, predominately loblolly pine (*Pinus taeda*), were used in each of the trial studies. The mill trial samples were collected either at the secondary refiner blowline or the transfer chest following the secondary refiner. The main pulp processing steps prior to sampling included chip washing, RT-chip pretreatment, primary and secondary pressurized refining.

Each refining line at Bowater Calhoun has a separate RT-chip pretreatment stage. The RT-chip pretreatment includes a MSD (Modular Screw Device) compression screw device with pressurized inlet. The chips are fed via a rotary valve into a pressurized conveyor, which in turn feeds the pressurized inlet housing of the compression screw device. The retention time (R) and inlet pressure (T) between the rotary valve and screw compression can be adjusted for process optimization. A plug zone without flights at the discharge of the screw is available for additional compression of the wood chips. The chips discharging from RT-pretreatment feed an inclined drain conveyor, which in turn feeds the plug screw feeder (PSF) inlet chute.

Mainline refining consists of two Andritz Twin 66 pressurized refiners (66-inch diameter) each with 25 MW motors. A pressurized stream splitter conveyor conveys the chips from the PSF to the primary refiner. The mainline refining motor loads were maintained at similar levels for each study. The objective was to evaluate changes in the chip pretreatment operating conditions, while maintaining refining conditions as similar as possible.

A similar pilot scale RT-chip pretreatment configuration as discussed above was used at the Andritz Research and Development Laboratory in Springfield, Ohio. Primary refining was conducted using an Andritz 36-1CP pressurized single disc refiner (36" diameter). Secondary refining was conducted using an Andritz 401 atmospheric double disc refiner.

All pulp samples were tested at the Andritz Research and Development Laboratory using standard Tappi test procedures. A 0.10 mm screen plate was used in the Pulmac Shive Analyzer for all tests. A FiberScan™ analyzer was used to measure average fiber length. An independent laboratory (Bowser Morner, Inc., Dayton, Ohio) conducted the DCM extractives and COD analysis

The microtome chip cross sections and SEM micrographs were conducted at the Department of Paper Science at UMIST, Manchester, UK.

Results

The wood supply to the Bowater Calhoun newsprint division historically generates higher pulp strength properties in the summer season compared to that obtained in the winter season. The wood quality during the spring and fall months undergoes somewhat of a transition in quality between these two seasons. Studies were conducted both during the winter and summer seasons, respectively. Results from both these periods will be discussed separately.

Winter

Preliminary pilot plant studies were conducted at the Andritz Research and Development Laboratory on pretreated wood chips supplied from Bowater Calhoun

newsprint division. The chips were produced at Calhoun with a pressure of 0.5 bar (7 psi) at the inlet of the RT Pressafiner. Non treated chips were also supplied for pretreatment using the pilot scale RT Pressafiner system. The chips were pretreated using the pilot scale press at an inlet pressure of 1.5 bar (22 psi). The primary objective was to identify if there was a benefit to increase the inlet pressure for the mill scale chip pretreatment. Table I compares the chip screen classification results for the pretreated chips produced at inlet pressures of 0.5 bar (7 psi) and 1.5 bar (22 psi). The chip size distribution prior to the chip pretreatment is also included in Table I. The compression level of the pilot scale RT Pressafiner was adjusted to achieve the same discharge solids content as that achieved at Bowater Calhoun. The compression is adjusted using four hydraulic restrictor pins that are available for compressing the chips at the discharge end of the screw device. The discharge solids content levels were 62.1% and 62.8% for the mill scale and pilot scale presses, respectively.

The RT-Calhoun chip samples produced at an inlet pressure of 0.5 bar had the highest percentage of fines through the 1/8" hole. The dry bulk density reduced following the chip pretreatment from 151 kg/m³ to 130 kg/m³.

TMP pulps were produced from the RT-Calhoun and RT-Springfield operating conditions. Both sets of chips were water impregnated and drained prior to refining. The pretreated chips were refined to a similar primary freeness, then secondary refined at several levels of specific energy. Table II compares the secondary refined pulp properties for both series at an interpolated freeness of 180 ml.

The pulps produced from the RT-Springfield chips at the higher inlet pressure (1.5 bar) had higher overall strength properties and long fiber content. The results suggested a higher level of damaged fibers and fines generated when operating the compression pretreatment at the lower inlet pressure.

A mill scale refining trial therefore was conducted in February 2000 to evaluate the impact of the inlet pressure of the RT Pressafiner pretreatment on refined pulp properties. Several inlet pressures were evaluated ranging from 0 bar, 0.7 bar (10 psi), 1.0 bar (15 psi) and 1.4 bar (20 psi). The system was also operated in bypass to evaluate pulp properties produced without the compressive pretreatment. Table III lists the operating conditions for each of the five pretreatment conditions. Table IV lists the pulp properties obtained at each of the five operating conditions. Each value in Table IV is an average of two secondary refiner blowline samples. The pulps were tested at the Andritz Research and Development Laboratory.

The pulps produced from the bypassed chips (no pretreatment) had the lowest tear index and long fiber content. The pulps produced at the highest

pretreatment inlet pressures (1.0 bar and 1.4 bar) had the highest tear index and long fiber content. The inlet pretreatment pressure did not appear to have an impact on the burst index and tensile index properties.

The DCM extractives content of the primary refined pulps and COD concentration of the primary pulp pressates are also reported in Table IV. The pulps produced from the precompressed chips averaged approximately 25% lower extractives content compared to the pulp produced without pretreatment. The DCM extractives and COD levels reduced with increases in the pretreatment inlet pressure from 0 bar to 0.7 bar to 1.4 bar. The pulp produced at 1.0 bar inlet pressure had extractives and COD levels outside the trend of the 0 bar, 0.7 bar and 1.4 bar pulps.

Several pulp properties were also monitored over a 12 day period from the Calhoun mill on refiner line 7 during operation with and without the chip compressive pretreatment. The average change in bulk, burst index, breaking length and tear index were -1.0%, +6.3%, +11.6% and +5.0%, respectively.

Summer

Additional studies were conducted in August 2000 to evaluate the impact of chip pretreatment on specific energy consumption and pulp properties. Production rate determinations were conducted at the line 7 transfer chest with and without the wood chips going through the compression pretreatment. The production rates were obtained by flow and consistency measurements from the line 7 mainline transfer chest. Four inlet pressure levels were evaluated (0.4 bar, 0.7 bar, 1.0 bar, and 1.4 bar).

Table V lists the operating conditions for each pretreatment condition and in bypass. A reduction in production rate was observed when operating in bypass versus passing through chip pretreatment.

A reduction in mainline refiner specific energy was observed with and without the chip pretreatment, the average reduction was 147 kWh/ODMT (6.8 hpd/adst). Accounting for the energy applied in the chip compression screw, the actual or net reduction in specific energy was 115 kWh/ODMT (5.3 hpd/adst).

Table VI illustrates the mainline refiner pulp properties obtained in bypass and at the four pretreatment inlet pressures.

The four pretreated series averaged almost 1 mN.m²/g higher tear index compared to the refiner series produced with the bypassed chips. The burst index, tensile index and optical properties were similar with or without the chip pretreatment. Both studies during the winter and summer periods produced pulps with a higher tear index with the chip pretreatment at pressurized inlet conditions compared to the bypass. The winter study, however, indicated an increase in tear index with

Increasing inlet pressure; whereas the summer study did not show a further increase in tear index with increasing inlet pressure. Referring to the summer study results (See Table VI), the tear index values were significantly higher compared to the winter study results (See Table IV). The summer study tear values ranged from 10.2 mN.m²/g to 10.5 mN.m²/g, compared to the winter study tear values of 7.0 mN.m²/g to 8.4 mN.m²/g at pretreatment inlet pressures between 0.7 bar to 1.4 bar. A superior wood chip furnish during the summer period may explain the good results at lower pretreatment inlet pressures; whereas the winter chip furnish may require higher inlet pressurization to prevent damage to the fibers during chip compression.

Refiner load variation

Figure 2 illustrates the line 7 primary (top trend) and secondary (bottom trend) refiner motor loads on September 27, 2000 with the chip pretreatment off line (left side) and on line (right side). A reduction in the primary and secondary refiner load swings is observed when operating with chip pretreatment versus "as is" wood chips. This is attributed primarily due to a more uniform bulk density, moisture content and a smaller chip size distribution feeding the primary refining stage.

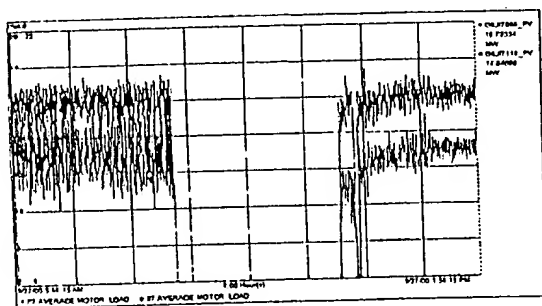


FIGURE 2. LINE 7 REFINER MOTOR LOADS BEFORE AND AFTER PRETREATMENT

The average mainline refiner loads and standard deviations from Figure 2 are listed in Table VII. The motor load data was obtained from Bowater Calhoun's PI data acquisition system at one-second intervals. A significant reduction in the motor load standard deviations is observed when operating with the pretreated wood chips.

Plug Screw Feeder Torque

A plug screw feeder (PSF) feeds chips to the stream splitter retention conveyor which in turn feeds the Twin 66 refiner. TABLE VIII compares the PSF torque averages and standard deviations with line 7 operating in bypass and line 8 with chip pretreatment. The PSF speed was 40 rpm for both refining lines 7 and 8. A

reduction in both the magnitude and variability of PSF motor torque was observed when operating with chip pretreatment compared to operating in bypass.

Figure 3 illustrates the PSF motor torque across a 24-hour period for line 7 (chips in bypass) and line 8 (chip pretreatment). The line 7 trend is located above and line 8 trend below. The line 8 trend was more uniform with less peak to peak variation. The improved refiner load stability is believed to be largely influenced by a more uniform delivery of chips from the PSF to the refiner.

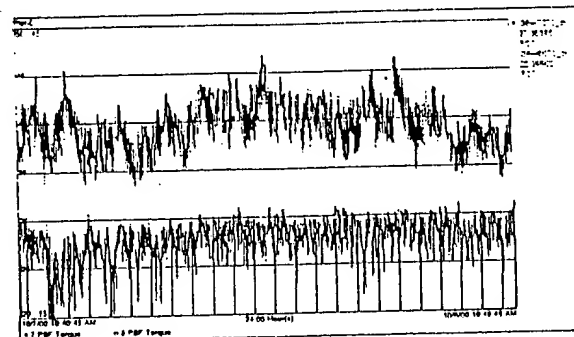


FIGURE 3. PSF MOTOR TORQUE WITH/WITHOUT CHIP PRETREATMENT

Discussion

Studies have been conducted to quantify the energy required to liberate a single fiber from wood. Koran measured the energy to liberate fibers from black spruce specimens by tensile loading perpendicular to the long axis of the fiber, across a range of temperatures⁷. He reported a value of 1.5 ergs at 120 °C for the fiber separation energy, reducing to 0.5 ergs at 170 °C. Such values would indicate the energy consumed in fiber liberation is a very small fraction (<1%) of the total energy consumed during refining. In actuality, a significant amount of energy is required to conform the fiber to the desired degree of fiber development. This is largely due to the mechanical losses incurred in fracturing wood, particularly when this involves straining the lignin component⁸. In other words, there is a large viscoelastic deformation energy or mechanical loss incurred when applying energy to develop more exposed fiber surfaces. The major part of the energy transmitted to the wood is dissipated as heat because the lignin component of wood is a viscoelastic material. The high specific energy requirement in mechanical pulping is largely a consequence for retaining lignin in the pulp.

Energy applied to the fibers is expended in two stages during refining, firstly, energy consumed in defibration, and secondly, energy expended in additional fiber modifications (fibrillation), to meet pulp property requirements. Koran's separation energy was based on

the former stage, defibration. Most of the energy is consumed in the latter or fibrillation stage.

Refiner mechanical pulping has been described as a highly specialized attrition process with the objectives of producing fibers with specific physical properties. Refining generates an extremely high number of cyclical refiner bar impacts during which the fiber is repeatedly compressed and relaxed. A high number of repeated compressive cycles are necessary to liberate individual fibers from the wood chip structure. A large amount of energy is dissipated as heat in the refining process, which is typically recovered in the form of steam. Unfortunately the cost of electrical energy is typically much higher than the heat value of the recovered steam.

In order to truly improve refining efficiency, the actual electrical energy applied to the fiber structure must decrease while attaining a similar or better level of fiber development. Salmén equated this energy reduction to a reduction in the compressive cycles necessary to liberate a fiber from the wood constituents⁹. An objective of the chip pretreatment is to sufficiently partially defibrate the pine tracheids (fibers) such that the number of compressive cycles required to liberate the fibers is reduced. This would in turn directly reduce the energy requirements in the refining process.

Wood chips are exposed to a high level of compression and shear forces during chip pretreatment in the screw device. The chips are re-oriented and undergo stress in both the axial and lateral positions, as they proceed to the discharge of the compression screw. Figures 4 and 5 illustrate microtome cross sections of pine latewood tracheids. The SEM pictures were taken from untreated and pretreated wood chips from Bowater Calhoun.

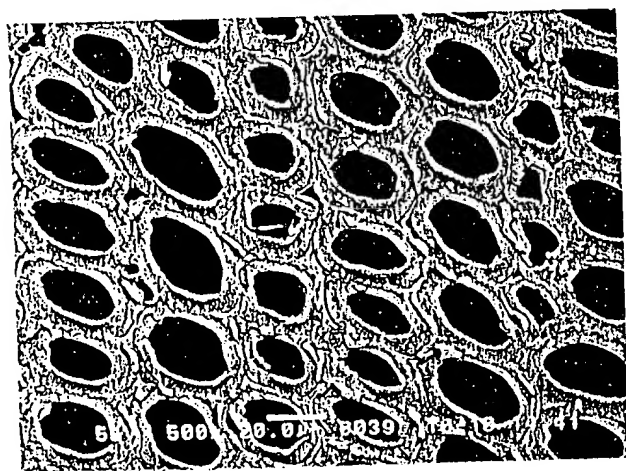


FIGURE 4. UNTREATED CHIPS (LATEWOOD) 500 x

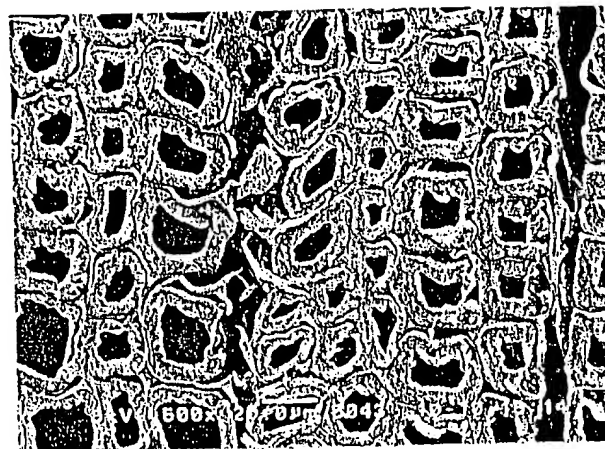


FIGURE 5. TREATED (LATEWOOD) CHIPS 500 x

The pretreated cross sectional image clearly shows a large number of partially defibrated fibers. Frazier and Williams study¹⁰ on axial compression of western hemlock wood chips revealed a high degree of separation at the S1-S2 interface, which may be related to the local stress concentrations at the interface of the two fiber wall layers. Kure et al. study on compressed Norway spruce chips⁵ found the primary area of separation or fracture was somewhere in the area between the middle lamella, the primary wall and the S1 layer. Many of the separated pine latewood tracheids in Figure 5 have a detached middle lamella with a portion of the outer fiber wall attached. A number of the fracture or separation zones appear deeper into the S2 layer, however, most of the separation appears at the outer S1 and P1 material. In some cases deformation and actual rupture of the latewood fibers is observed. This is of particular benefit to reduce the stiffness and improve collapse of the thicker walled fibers following refining.

Figure 6 illustrates an earlywood microtome cross section of a pine wood chip following the chip pretreatment. The thinner earlywood tracheids were more deformed; however, partial defibration was less pronounced compared to the latewood component. This observation has been previously reported on spruce chips following a similar chip compressive treatment⁵.

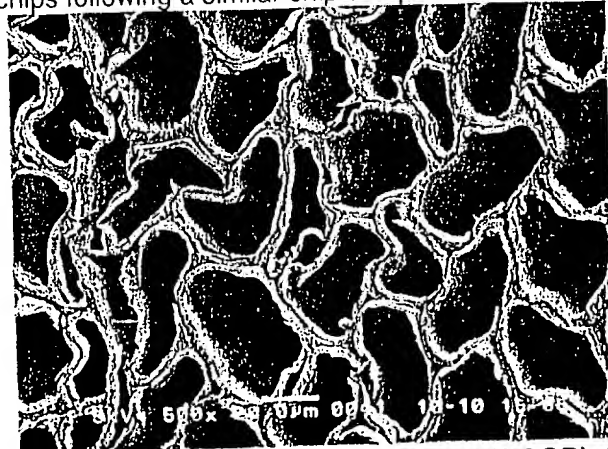


FIGURE 6. TREATED CHIPS (EARLYWOOD) 500 x

Lignin absorbs energy as a viscoelastic material during refining. Detachment of a portion of the middle lamella during partial defibration may reduce the compressive cycles and hence energy necessary during disc refining. Modification of the fiber-lignin structure prior to refining may therefore be an effective means of reducing the energy consequence for retaining lignin in mechanical pulp.

Conclusions

- Mill scale results from the Bowater Calhoun newsprint division were presented using a pressurized compression chip pretreatment process.
- The pulps produced from the precompressed chips averaged approximately 25% less extractives content compared to pulps produced without pretreatment.
- An average reduction in total specific energy of approximately 115 kWh/ODMT was observed using the chip precompression stage.
- TMP pulps produced using the chip pretreatment had a higher tear index compared to pulps produced from normal wood chips. Further increases in the tear index were observed in the winter study when increasing the pretreatment inlet pressure from 0.7 bar to 1.4 bar. The summer study maintained a similar tear index at inlet pressures between 0.4 bar and 1.4 bar.
- The refiner motor load was more stable when operating with chip pretreatment versus untreated wood chips.
- The latewood pine tracheids from the pretreated chips exhibited a significant level of partial defibration. The earlywood component exhibited a higher degree of deformation with less defibration. Modification of the wood chip structure prior to refining may help explain the related reduction in specific energy.

Acknowledgments

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TABLE I. CHIP SCREEN CLASSIFICATION AND BULK DENSITY RESULTS

Nomenclature	Inlet Pressure (bar)	%+1"	%+3/4"	%+5/8"	%+1/2"	%+1/4"	%+1/8"	%-1/8"	Dry Bulk Density (kg/m ³)
Calhoun	-	21.39	27.07	15.76	14.03	18.49	2.86	0.40	151
RT-Calhoun	0.5	7.35	15.28	13.83	15.28	34.02	9.83	4.41	130
RT-Springfield	1.5	5.60	17.78	16.26	20.45	35.62	4.08	0.21	137

RT-Calhoun = chips pretreated at Bowater Calhoun

RT-Springfield = chips pretreated at Andritz Inc.

TABLE II. PULP PROPERTIES-RT CALHOUN (0.5 BAR) AND RT-SPRINGFIELD (1.5 BAR) CHIPS

	RT-Calhoun	RT-Springfield
Furnish	695	701
Primary freeness (ml)	41.7	41.6
Primary consistency (%)	4.12	3.92
Primary shive content (%)		
Secondary freeness (ml)	180	180
Bulk (cm ³ /g)	3.56	3.22
Burst index (kPa.m ² /g)	0.98	1.24
Tear index (mN.m ² /g)	6.2	7.5
Tensile index (Nm/g)	22.6	25.9
Stretch (%)	1.47	1.69
T.E.A. (J/m ²)	14.45	19.10
Opacity (%)	91.5	91.6
Scattering coefficient (m ² /kg)	45.7	47.2
Shive content (%)	0.23	0.11
+28 mesh (%)	26.5	30.7
-200 mesh (%)	31.8	27.0
Specific energy (kWh/ODMT)	2122	2063

TABLE III. CHIP PRETREATMENT AND REFINER OPERATING CONDITIONS

	Bypass	0	0.7	1.0	1.4
Pretreated pressure (bar)	NA	3489	4829	5907	6448
Steam flow (lb./hr)	NA	69	62	56	46
Screw torque (%)	19.2	19.8	19.4	19.8	19.6
Primary refiner load (mw)	45.5	46.6	45.6	46.5	46.3
Primary refiner consistency (%)	14.4	16.3	15.5	15.7	16.5
Secondary refiner load (mw)	50.1	50.0	47.6	49.6	50.1
Secondary refiner consistency (%)					

TABLE IV. MAINLINE REFINER PULP PROPERTIES - EFFECT OF PRETREATMENT PRESSURE

	Bypass	0	0.7	1.0	1.4
Pretreatment pressure (bar)	156	153	152	146	176
Freeness (ml)	3.4	3.3	3.4	3.3	3.5
Bulk (cm ³ /g)	1.2	1.3	1.1	1.1	1.2
Burst index (kPa.m ² /g)	6.8	7.2	7.0	8.1	8.4
Tear index (mN.m ² /g)	23.3	24.3	24.2	23.1	22.3
Tensile index (Nm/g)	92.0	92.0	93.6	92.4	91.2
Opacity (%)	54.5	51.1	54.1	53.2	49.8
Scattering Coefficient (m ² /kg)	0.2	0.5	0.10	0.3	0.4
Shive content (%)	32.3	32.8	34.0	34.7	37.7
+28 mesh (%)	30.3	29.2	27.7	28.8	26.6
-200 mesh (%)	2.69	2.08	1.97	(2.13)	1.88
DCM extractives	310	310	276	(172)	241
COD (mg/l)					

↳ 0 psi = atmospheric pretreatment
 ↳ Bypass = NO pretreatment

TABLE V. CHIP PRETREATMENT AND REFINER OPERATING CONDITIONS

	0.4	0.7	1.0	1.4	Bypass
Pretreatment pressure (bar)	531	521	530	542	489
Production rate (adstpd)	439	431	438	448	404
Production rate (odmtpd)	690	622	562	471	-
RT Pressafiner screw load (kW)	20.1	20.0	20.1	20.0	20.0
Primary refiner load (mw)	42	42	42	42	42
Plug screw feeder (rpm)	14.9	15.2	15.1	15.1	14.9
Secondary refiner load (mw)	1914	1959	1928	1879	2067
Refiner Specific energy (kWh/ODMT)	1952	1994	1959	1904	2067
Total Specific Energy (kWh/ODMT) *	244	256	261	254	265
Freeness (ml)					

*Includes RT-pretreatment + mainline refining.

(SUMMER)

TABLE VI. MAINLINE REFINER PULP PROPERTIES - EFFECT OF PRETREATMENT PRESSURE

	0.4	0.7	1.0	1.4	Bypass
Pretreatment pressure (bar)	244	250	261	254	265
Freeness (ml)	3.69	3.70	3.77	3.79	3.81
Bulk (cm ³ /g)	1.29	1.31	1.25	1.26	1.25
Burst index (kPa.m ² /g)	10.4	10.2	10.5	10.4	9.5
Tear index (mN.m ² /g)	24.4	24.5	23.8	23.6	23.2
Tensile index (Nm/g)	90.2	90.1	90.2	89.5	89.2
Opacity (%)	48.7	49.1	49.0	48.7	48.7
Scattering coefficient (m ² /kg)	52.2	52.3	52.7	52.8	52.8
ISO Brightness	0.68	0.80	0.87	0.81	0.74
Shive content (%)	36.9	38.8	38.1	37.9	39.8
+28 mesh (%)	31.8	30.3	30.3	32.4	27.6
-200 mesh (%)	2.07	2.10	2.09	2.02	2.05
LW average (mm)					

Note: each value in the table is the average of four transfer chest samples.

No pretreatment →

TABLE VII. LINE 7 REFINER LOAD STANDARD DEVIATION

Refining Stage	Bypass		Pretreatment	
	Primary	Secondary	Primary	Secondary
Average (mw)	16.01	15.03	16.04	15.02
Std. Deviation	0.45	0.87	0.30	0.33

Bypass time interval: 5:00 A.M.-7:00 A.M. September 27, 2000

Pretreatment time interval: 1:00 P.M.-3:00 P.M. September 27, 2000

TABLE VIII. PSF MOTOR TORQUE (%)

	Bypass	Pretreatment
Average	39.4	22.6
Std. Deviation	2.2	1.7
Refiner Line	7	8

Bypass time interval: 10:40 A.M., October 7 to 10:40 A.M. October 8

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